AAS
Planetary Division

1

A Startup

- Recently heard of conference date
- Hetheral put me on agenda so late in planning
- The more I thought about this meeting the more excited I have become about the opportunity to talk to you
- Exciting things are happening at NASA. We are in the midst of a revolution in ~~our~~ restructuring our planetary prgm — The opportunities for scientific discovery & technological breakthroughs are limitless

set goals and seeing results

- ~~The changes have been amazing wide in the last months~~

existing possible

(travel to centers
(people our most important asset
JPL ARC

- $\boxed{\text{last 2 1/2 years}}$

(2)

other key investments

- external focus to stabilize program & align with America

Presidential themes
- fiscal realities drive
- much more robust planetary science
dazzling discovery

- Goals of space flight clear to me
• Ask people want better life children
• Bold & noble tasks to explore final frontier space

(1) Provide promise of long term opportunity for future generations

better life for children

• sustained long term economic ~~growth~~ opportunity thru major science & technology breakthrus
• better understanding of our own environment
natural forces
human induced forces
• abundant resources to sustain life
• open space frontier for commerce

(2) Intellectual enrichment
formation & evolution

PS 93 asteroids, red spot
2,379,816 7/15 - 10/31 logged on internet
all state LA

Reform

3

just to
find one

(3) Provide hope we don't live in
a closed planetary system.
law of diminishing returns
(4) Inspiration for future generations
enrich life

couch potatoes
recreation/entertainment

astronauts

goals
role models
risk
spur imagination!

(5) catalytic action for understanding
inhabitants on our small
planet

Brazil
Japan
Argentina

Russia
Ukraine
Kazakhstan

4

1. hold on to past
2. adapt to change and blaze a ~~fresh~~ new ~~trail~~ trail

Reengineer
continuous improvement
cooperation not just competition
cancel weakest pigments
Darwin rules
Survival of fittest.

~~Rules~~
~~1. Relevance~~

Vision

~~Dreams & Numbers~~
10 numbers / year
time of century
can accomplish with

CHART NOW

5

see chart & talk

more is less
revolution not just evolution
confirm –
Diversity
funding # Do what we say we will do

a Discovery 1995–2000

< 150 M
open 100's kg
36 Mos thru post launch stabilize
≥ 1 launch/yr

b Return to Mars
visit fin
4 for less than price of
one 650 300 2 96
600 370 1 Dec 98
1 Jan 99

94 Discovery
c Not enough to handle
real tough missions

↓ input output ↑

6

500 → 50 kg
Multiple s/c per small LV
Build & integrate in clean room
Highly Autonomous

automatic
testing
onboard

• autonomous thinking systems
human/machine integration
Millers rule 7±2
- ground based people for ops approach zero in limit
narrow → broadband
- robust terminal operations
- ~~human~~ step to human ops
• adaptive machines like human body
• live off land experiments
• planetary body reconnaissance
ALLEG discussion
find resources fingerprint
hyperspectral components
find landing sites

- spacecraft avionics & spacecraft on chip
- advanced power systems
  - 4x efficiency
  - 1/4 power consumption
- advanced lightweight materials
- MEMS & microelectronics

Don't forget other systems

- telescope technology
- regenerative life support
- clean microecological systems
- micro molecular surgery gene activation

(a) Fabrication
Post Cassini

clearroom bench v.s. large fach
glovebox v.s. lifting cranes & assy stands

MEMS chips v.s black boxes wired together

10's people v.s. 100's people

rapid prototype software v.s. custom one of a kind

(b) E.g. Science
Planetary Integrated Camera v.s. Voyager scan platform

~~X~~ .5 kg v.s. 100 kg
~~5~~ 1.5 W v.s. 7000
sensitivity 1000X better

map cold body
spectral coverage 2-3 times

(c) spacecraft on chip

MEMS
VLSI
high energy density batteries
Integrated antennae

1000 g spacecraft <
McDonalds 1/4 pounder

deploy fleets from carrier vehicle

- unprecendented accuracy
  in measuring
  spatial/temporal variations
  in planetary magnetic
  fields

(NASA esa cluster more
expensive less capable)

- Much more detailed
  measurements of solar wind
  ionospheres

- Global climatology
- Global seismology and geology

webster dictionary defines
revolutionary

a sudden or radical change
in a situation

That's what we are
after

possibilities later

Moon vault

(E) • 4 mission

(orbiter ~~…~~ Dec 98
(lander ~~…~~ Jan 99

700 + < 200

(A) < 900

(E) Ideal letter from MO

$\boxed{\begin{array}{ll} \text{MO} & 1000\text{ kg} \\ \text{S}^{t} & 1900\text{ kg} \end{array}}$

cruise

600
650
300
370

∇

Heard about conference a few
weeks ago

Flattered you put me on agenda
so late in the planning

The more I thought about this
opportunity the more excited
I've become

more is less
revolution not just evolution
cooperation not just competition
Diversity in people places & ideas
Do what we say we will do

MC 1B
4 new Mars < 900 z 96 Dec 98/Dec 89

1000 vs. 650 | 300 ⇒ more is less
600 | 370 2000

look at chart & talk

DID NOT USE -
USED HANDWRITTEN NOTES

Talking Points
Division for Planetary Sciences, American Astronomical Society
Nov. 1, 1994

• Two main themes tonight:

--NASA is committed to continuing great planetary science missions.

--Fiscal realities have changed. Money available for planetary science will be far below the levels we're used to. To do great science, we have to have a revolution—a revolution that will let us do more with less.

• The nation needs smaller, lighter, cheaper initiatives. Goal is not simply to spend less money and complete projects more quickly. The goal is to do all that and have the end result be <u>better science</u>.

• Doing things cheaper and more quickly is not a pie-in-the-sky dream. It's a must. NASA, and every other Federal Agency, is facing severe budget pressures -- every dollar under intense scrutiny.

--Since 1991, Congress has capped all discretionary spending at the mid-$540 billion range, and that will last through 1998.

--NASA has taken a 30% cut in two years, and looking at a flat budget over the next five years. That means we'll lose between $400 and $500 million dollars in buying power a year.

• Still, we are maintaining our commitment to science. NASA science programs have increased from $3.3 billion in FY 94 to $3.5 billion in FY 95, the highest level ever.

Past, present, future

• Typical old-style Battlestar Galactica planetary mission:

--$1 billion + cost, mass up to 2000 kg.

--Dedicated Titan IV class ELV or shuttle

--Systems behind state-of-the-art due to long development times

--Large ground-based infrastructure needed for assembly and launch prep

--Labor-intensive mission operations

--Launch one mission every 2-3 years

• Disaster for planetary science if we continued this approach.

--The budget will not support this type of mission. Best we could hope for is some kind of flyby mission.

• Where we are now: in our planetary program, we now have 5 new missions planned.

Near
Pathfinder) 96
MGS
lander) 98
MGS

• Typical Discovery class mission 1995-2000
  --$150 million (or less), $35 million operations
  --Mass =hundreds kg
  --Dedicated Delta (or smaller) ELV
  --36 months from award thru post-launch shakedown; Mix of mature and advanced technology
  --"Clementine"-style mission ops personnel requirements
  --Launch one per year

• Obviously miniaturizing and reducing mission scope lets us do science we otherwise might not be able to afford.
  --But this approach alone would eventually reach point of diminishing returns. We could perform missions, but they would not really be scientifically valuable.

• The first real solution is what we're planning for 2000 and beyond. Spacecraft that have advances in many key technologies. Typical planetary mission post-2000:
  --Cost =$tens of millions

--Mass = tens of kilograms
--Multiple spacecraft per small ELV
--Short development time, advanced technology systems
--Build/integrate on cleanroom lab bench
--Highly autonomous

Closer Look: post-2000 vs. flagship class

• Remember that our goal is not just to make planetary spacecraft smaller and cheaper to launch. We must give them capabilities equal to or better than the probes that have produced such great science in the past.

• Revolutionary advances in spacecraft technologies affect more than just science capabilities. Impact spacecraft from assembly thru end-of-mission.

• Example: Post-2000 fabrication/test techniques vs. Galileo/Cassini:
--Assembled in cleanroom lab or bench vs. large "factory" facility
--Glove-box like environment vs. large lifting cranes, assembly stands
--Entire systems fabricated as MEMS chips vs. black box systems wired together

--Rapid software development using DoD/commercial methods vs. custom, one-of-a kind flight software.
--Tens of people vs. hundreds for Flagship-class.

• These are the type of advances that will let us produce and launch an armada of spacecraft for the most ambitious exploration of solar system ever. Eventually, we plan to launch at the rate of one per month. Many, many more opportunities for PIs than today; you won't spend your whole career on one project.

• Example: Post-2000 mission ops vs. Magellan
--<30 people vs. Magellan's 300 (at peak)
--Autonomous optical navigation using pre-loaded star/planet/asteroid maps vs. radio-based navigation instructions
--Onboard health, status, fault monitoring vs. ground-based monitoring
--Event-driven, goal-directed spacecraft sequencing vs. time-based, open-loop.

• Making the spacecraft as autonomous as possible obviously cuts cost, but also makes for more efficient operations. PIs also would have more direct relationship with their science instruments because the ground and space infrastructure is essentially transparent.

• Example: Science at Triton. Compare capabilities of Planetary Integrated Camera Spectrometer (PICS) being developed for NASA's future planetary spacecraft vs. Voyager scan platform.

--PICS, 5 kg vs. Voyager 100 kg

--PICS, 1.5w power vs. Voyager 70w

--PICS visible imaging 1000 times more sensitive.

--PICS sensitivity allows both UV and IR imaging spectrometry. Could map cold body like Triton; Voyager could not.

--PICS spectral coverage 2-3 times greater, less geometric distortion.

• As planetary scientists, imagine what you could do with such capabilities. We will be able to optimize the spacecraft instruments for the particular conditions of the body to be studied.

• Example: Communications capability for post-2000 vs. "Flagship" class. Uses Multi-Chip Modules with 3-D stacking and MEMS :

--Mass 2 kg vs. Cassini, 6 kg.

--100 to 1 data compression vs. <30 to 1 for Galileo

--Eventually, optical communications system would allow 20 gb data streams—100 times current capabilities

• Such revolutions in data handling would let us deploy a constellation of small, widely-spaced platforms that would function as a giant "virtual" spacecraft.

--One potential application: interferometry to find Earthlike extrasolar planets.

• Advanced microspacecraft technologies (typified by "New Millennium" approach) allow orders of magnitude reductions in mass & cost. Still real "breakthrough" science requires still another leap forward to "spacecraft on a chip."

• Ultimate goal is to incorporate innovative architectures and microdevices to give us capabilities we don't have today.

• Example of technologies/architectures:

--MEMS

--VLSI circuitry

--High-energy density batteries

--Integrated antenna

• Result is a 100g spacecraft-on-a-chip: weighs less than a McDonald's quarter-pounder.

• Deploy fleets of these spacecraft from carrier vehicle. Potential missions:

--Unprecedented accuracy in measuring spatial/temporal variations in planetary magnetic fields; NASA/ESA Cluster is more expensive, less capable.

--Much more detailed measurements of ionospheres, solar wind

--Global climatology

--Global seismology and geology

• These points are particularly important because there are two drivers for our planetary science program: pure science <u>and</u> the need to perform robotic precursor missions before deciding on our next human spaceflight goal.

• Four possible destinations and potential resources that robotic missions will look for: (See "Resources Available" charts from Code SL)

• Webster's Dictionary defines "revolution" as "a sudden or radical change in a situation." That's what we're after at NASA, a true technological revolution. A "sudden, radical change" in what we're asking from technology. We're going to use state-of-the-art technology to do incredible, amazing things, and we're going to do it "better, faster, cheaper" than ever before.